

# ~~METHODS OF HEAT TRANSFER:~~

HEATING PROCESSES (heat released to surroundings)

- Freezing of liquid to solid.
- Condensation of vapor to liquid (reverse of boiling or evaporation).
- Compression of a gas.
- Condensation of vapor to solid (reverse of sublimation).

COOLING PROCESSES (heat absorbed from surroundings)

- Boiling of liquid to vapor.
- Evaporation of liquid to vapor.
- Melting of solid to liquid.
- Sublimation of solid to vapor.
- Expansion of a gas.

## Chapter 18:

First Law of Thermodynamics:  $\Delta U = Q + W$ . The change in internal energy of a system equals the heat *added* to the system plus the work done *on* the system.

A good test case is an ideal gas in a cylinder with a movable piston.

The work done ON the gas is

$$W = - \int_{V_1}^{V_2} p dV,$$

which is  $< 0$  if  $V_2 > V_1$  (expansion), and  $> 0$  if  $V_1 > V_2$  (compression).

### Types of Thermodynamic Processes:

- Isothermal,  $\Delta T = 0$ .
- Constant Volume,  $\Delta V = 0$ .
- Isobaric,  $\Delta p = 0$ .
- Adiabatic,  $Q = 0$ .

### ISOTHERMAL PROCESS:

$$W = -NkT \ln \left[ \frac{V_2}{V_1} \right].$$

For an ideal gas,  $\Delta T = 0$  means  $\Delta U = 0$ .

## CONSTANT VOLUME PROCESS:

$$\Delta U = Q$$

since no work is done on or by the system.

If  $Q = nC_v\Delta T$  then  $\Delta U = nC_v\Delta T$ .

## ISOBARIC PROCESS:

$$W = -p\Delta V, \quad Q = nC_v\Delta T + p\Delta V,$$

and using the Ideal Gas Law,

$$Q = n(C_v + R)\Delta T \equiv nC_p\Delta T.$$

## ADIABATIC PROCESS:

$$\Delta U = W, \text{ since } Q = 0.$$

Using the Ideal Gas Law gives

$$\frac{dp}{p} + \frac{C_p}{C_v} \frac{dV}{V} = 0,$$

so that

$$pV^\gamma = \text{const.}, \quad TV^{\gamma-1} = \text{const.}$$

where  $\gamma = C_p/C_v$ .

## *Equipartition of Energy:*

For an ideal gas,  $U = (3/2)NkT = (3/2)nRT$ ,

So for a monatomic gas,  $C_v = (3/2)R$ .

For every additional degree of freedom, add  $(1/2)kT$  to  $U$ .

Thus for an atom in a solid,  $C_v = 3R$ .

For a diatomic molecule at normal temperatures,  $C_v = (5/2)R$ .

## Chapter 19:

It is an obvious fact of nature that all readily-observable processes are *irreversible*. There is an arrow of time, flowing from past to future. Yet physicists quickly realized that it is by no means obvious where the irreversibility comes from. All fundamental laws of physics are time-reversal invariant, that is they have the same form if  $t$  is replaced everywhere by  $-t$ . And the fundamental constants of nature are time-independent. So what is the origin of irreversibility of natural processes?

**Thermodynamic Entropy:** Clausius pointed out that the quantity

$$dS = \frac{dQ}{T}$$

irreversibly increases in thermodynamic processes. In the course of any physical process,  $\Delta S > 0$  unless it is already at a maximum initially.

**Entropy:** Boltzmann pointed out that entropy is directly related to probability.

$$S = k \ln N_{\text{ms}}.$$

Here  $N_{\text{ms}}$  is the number of microstates that make up a given state of the system. So when you say

that “entropy increases,” you are merely saying that a system subjected to accident tends to be left in a more probable state than the one it started in.

**The Second Law of Thermodynamics:**  
In the course of a process,  $\Delta S > 0$ , in general.

### **Heat Engine:**

Heat  $Q_h$  is extracted from  $T_h$  and a portion used to do work  $W$ . The remainder,  $Q_c$ , is expelled into an environment at  $T_c$ .

From energy conservation  $Q_h = W + Q_c$ . If we define the efficiency as  $\epsilon = W/Q_h$ , then we immediately find

$$\epsilon = 1 - \left[ \frac{Q_c}{Q_h} \right].$$

Because  $\Delta S > 0$  in any cycle of the engine, it is impossible for  $W = Q_h$  and  $\epsilon = 1$ .

### **Carnot Efficiency:**

Physicists noticed that despite all engineering improvements the efficiency of all heat engines remained small. Carnot suggested comparing real engines to an imaginary engine for which  $\Delta S = 0$ .

Then

$$\Delta S = \frac{Q_c}{T_c} - \frac{Q_h}{T_h} = 0$$

so that  $(Q_h/T_h) = (Q_c/T_c)$  and therefore

$$\epsilon_c = 1 - \left[ \frac{T_c}{T_h} \right].$$

Typically  $\epsilon \simeq \epsilon_c/2$ .

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## Different Statements of the 2nd Law:

- No process can convert 100% of a heat flow into work.
- In a closed system, any  $\Delta T$  will eventually go to zero. [“Heat Death”]
- A system will wind up in more and more probable states as time goes by, unless it starts in a most probable state.
- All energy releases are eventually entirely dissipated as heat.
- All basic processes involving complex systems are irreversible. [“Time’s Arrow”] This does not necessarily apply to processes involving fundamental point particles.

Statistical Entropy  $S = k_B \ln N_{ms}$ .

Thermodynamic Entropy  $\Delta S = Q/T$ .



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EXAMPLES

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		}	3	4
		}	2	6
		}	1	4

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Total = 16